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A Low-Cost Transportable Ground Station for Capture and Processing of Direct Broadcast EOS Satellite Data

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ABSTRACT

The Earth Observing System (EOS), part of a cohesive national effort to study global change, will deploy a constellation of remote sensing spacecraft over a 15 year period. Science data from the EOS spacecraft will be processed and made available to a large community of earth scientists via NASA institutional facilities. A number of these spacecraft are also providing an additional interface to broadcast data directly to users. Direct broadcast of real-time science data from overhead spacecraft has valuable applications including validation of field measurements, planning science campaigns, and science and engineering education.

The success and usefulness of EOS direct broadcast depends largely on the end-user cost of receiving the data. To extend this capability to the largest possible user base, the cost of receiving ground stations must be as low as possible. To achieve this goal, NASA Goddard Space Flight Center is developing a prototype low-cost transportable ground station for EOS direct broadcast data based on Very Large Scale Integration (VLSI) components and pipelined, multi-processing architectures. The targeted reproduction cost of this system is less than $200K. This paper describes a prototype ground station and its constituent components.

1. INTRODUCTION

For a number of years, any organization equipped with a relatively low-cost weather ground station has been able to acquire imaging data directly from weather satellites. For these spacecraft, direct broadcast of data has been necessary to service a widely distributed and diverse user community. This method of delivering data to users has allowed weather data to be used world-wide in a variety of applications. NASA science missions, however, have generally lacked this method of data delivery. A number of factors have precluded the use of direct broadcast techniques in NASA science missions. Among these factors are past policies restricting public access to science data and the prohibitive cost of the ground station and processing equipment required for science missions.

For the Earth Observing System (EOS), NASA has adopted an open door policy allowing wider access to science data products. Over a 15 year period, EOS will deploy a constellation of low-earth orbiting remote sensing spacecraft to monitor the Earth's environment. Although all EOS instrument data will be captured, processed and made available through centralized NASA facilities, the data of select instruments will also be available through direct broadcast from EOS spacecraft. The first EOS spacecraft, EOS-AM1 which is planned for launch in 1998, will broadcast data from the MODIS instrument. Through this capability, users will be able to capture real-time MODIS images of their geographic region taken while the spacecraft is flying overhead.

The EOS direct broadcast capability can be very valuable to many different organizations. Scientists can use this capability to conduct or validate field measurements, plan corroborative campaigns, and observe rapidly changing conditions in the field. International meteorological and environmental agencies could take real-time measurements of the atmosphere, storm and flood status, water temperature and vegetation stress. International science partners will have the ability to perform engineering quality checks and scientific studies at their own analysis centers. [1] Academic institutions could use the ground station and the data collected by it to illustrate important topics in science and engineering education and to provide students with hands-on experience. In addition, all users could get a "quick look" at the data until they received it from NASA EOS institutional processing facilities.

The number of organizations that will have access to EOS direct broadcast depends largely on the end-user cost of the equipment required to acquire and process the data. In order to maximize the number of potential users, the cost of receiving ground stations must be made as low as possible. Major cost reductions can be gained by developing high integration components to perform the major system processing functions. Further cost reduction can be gained by recognizing that this class of ground station is not necessarily constrained by the same stringent requirements imposed on NASA institutional systems. By relaxing availability, fault tolerance, and redundancy requirements, additional cost reductions may be realized.

2. A LOW COST SOLUTION

NASA Goddard Space Flight Center is currently developing a low-cost solution to provide low-cost direct data access. This solution will demonstrate a prototype low-cost transportable ground acquisition and processing station for EOS direct broadcast data. This system will include four elements: an antenna, Radio Frequency (RF) processing equipment, Consultative Committee for Space Data Systems (CCSDS) protocol processing equipment, and a UNIX workstation containing an automated schedule-driven software package for system control and science data processing. The initial targeted reproduction cost for this direct broadcast acquisition system will be less than $200K with further cost reductions to be realized as the technology matures. Through the use of this system, users will have the ability to receive direct broadcast data for any capable spacecraft, track the spacecraft, acquire and process science data and analyze the data on a local workstation.

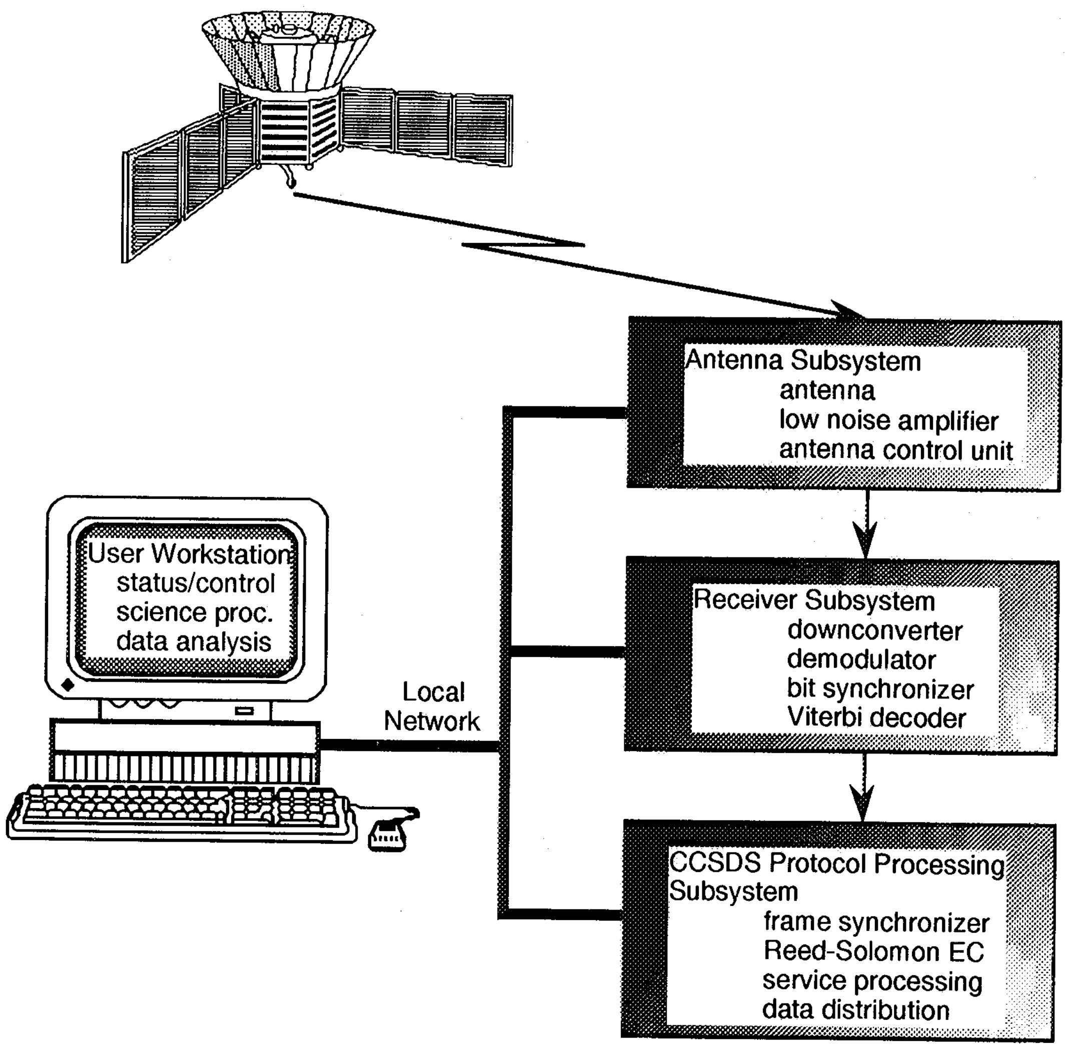

Figure 1. Subsystem Breakdown

The data rate for the EOS-AM spacecraft direct broadcast is approximately 13 Mbps. Based on current link budget calculations for this spacecraft, the minimum size dish antenna required to acquire this data will be about 2.5 meters. To keep the cost of the system low, the antenna will use programmed tracking. For transportability, the antenna will be easy to disassemble and store in a compact crate.

Future development will explore the use of phased array antennas to provide a smaller form factor, more reliable acquisition, and simpler setup and use. Initially a small, low complexity phased array antenna may be used to provide ephemeris data to the dish antenna. In the future, if sufficient levels of integration in RF processing components can be achieved at low cost, a phased array may be used to acquire science data. If this significant technical obstacle can be overcome, the use of a phased array antenna could present a superior method of acquiring science data. Phased arrays have a higher efficiency than a standard dish antenna and require no mechanical movement to track the spacecraft. Their planar structure also allows them more potential installation locations.

The RF processing equipment will down-convert the signal to Intermediate Frequency (IF) at which point the data is demodulated, bit synchronized, and error corrected using Viterbi decoding. The RF processing equipment outputs the digital data to the CCSDS protocol processing equipment.

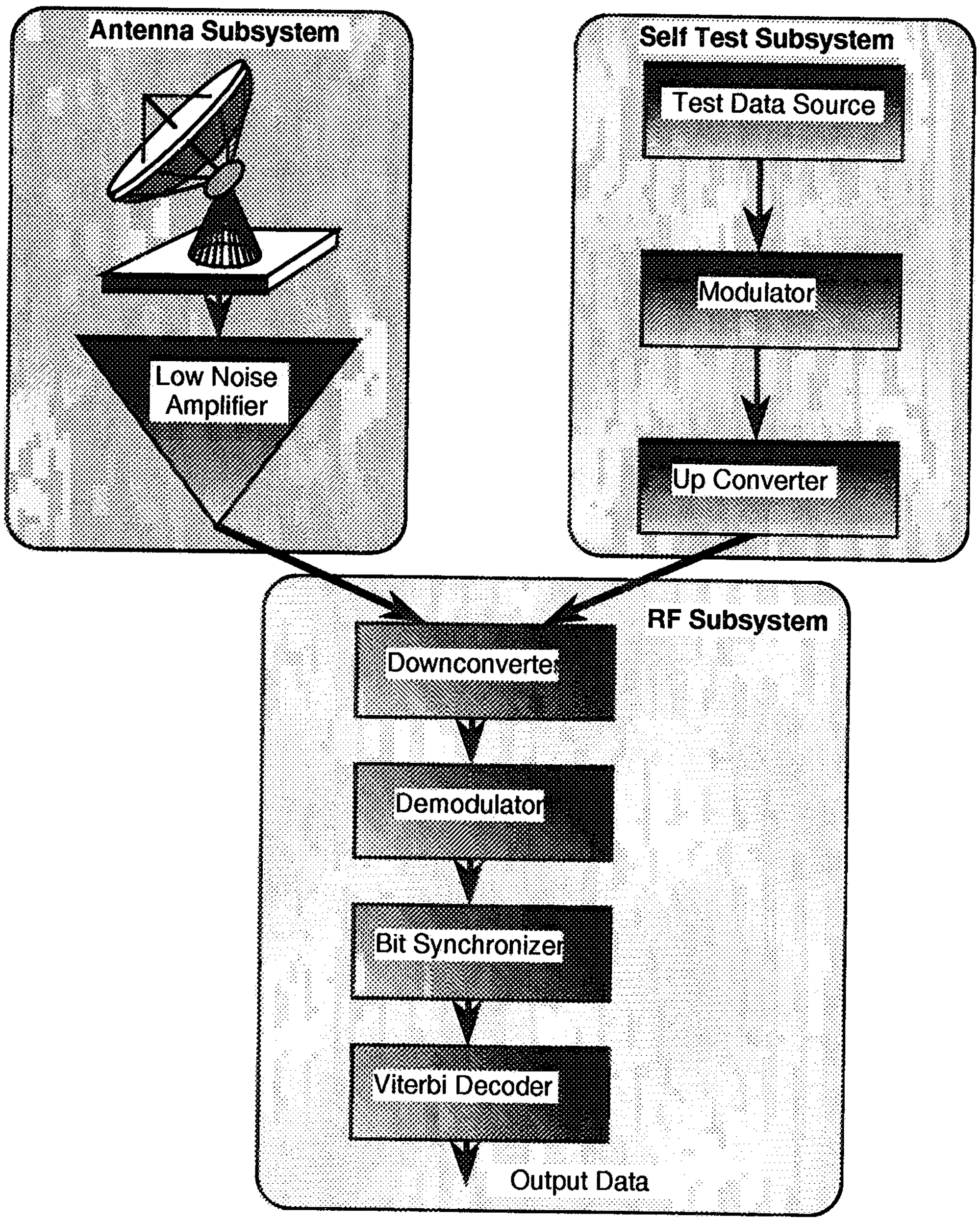

Figure 2. RF Processing Equipment Block Diagram

The CCSDS protocol processing equipment provides the following functionality: frame synchronization, Reed-Solomon error correction, CCSDS services processing and data routing to a user network. This equipment is a single printed circuit board containing three high performance ASICs to provide the major functionality of board. In addition, a high performance CPU is used to control the system and Peripheral Component Interface (PCI) bus slots are provided to allow the

user to expand the system with commercially available cards. The figure below shows a high level block diagram of the internal and external interfaces for the CCSDS Protocol Processor subsystem.

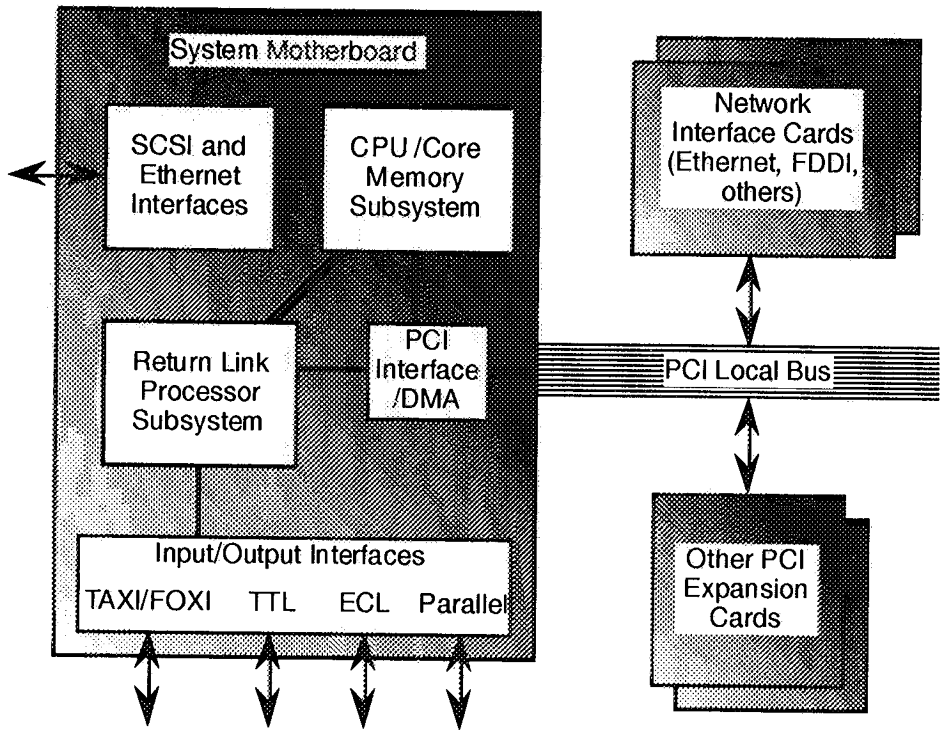

Figure 3. CCSDS Protocol Processing Subsystem

Figure 4 shows a more detailed block diagram of the functional blocks involved in CCSDS protocol processing. The data from the digital receiver subsystem is first synchronized using the frame sync, then corrected using Reed-Solomon error detection and correction. Finally, CCSDS service processing is performed on the synchronized frames. The data products can then be routed to a user network for further (Level 0 and up) processing.

The CCSDS Protocol Processing subsystem also accumulates information on the data quality and maintains statistics on such parameters as number of frames processed, data rate, number of packets processed, etc. Additionally, the subsystem has the ability to perform an automated self-test that can isolate a subsystem error to a functional block.

An important capability of the CCSDS Protocol Processing subsystem is the ability to accept commercially available PCI card for system expansion. A typical application may involve the installation of a high performance network card (e.g. ATM) into the system to allow interface to a user network. In this manner, the system is able to interface to many different network installations. This allows users to receive the data products and perform higher level processing on them locally. The CCSDS Protocol Processing subsystem has the ability to route data to a number of users based on specific criteria (SCID/VCID, APID, etc.) allowing it to handle multiple users requirements. Also note that a ethernet interface is included on the motherboard for lower rate data requirements and for system status and control functions.

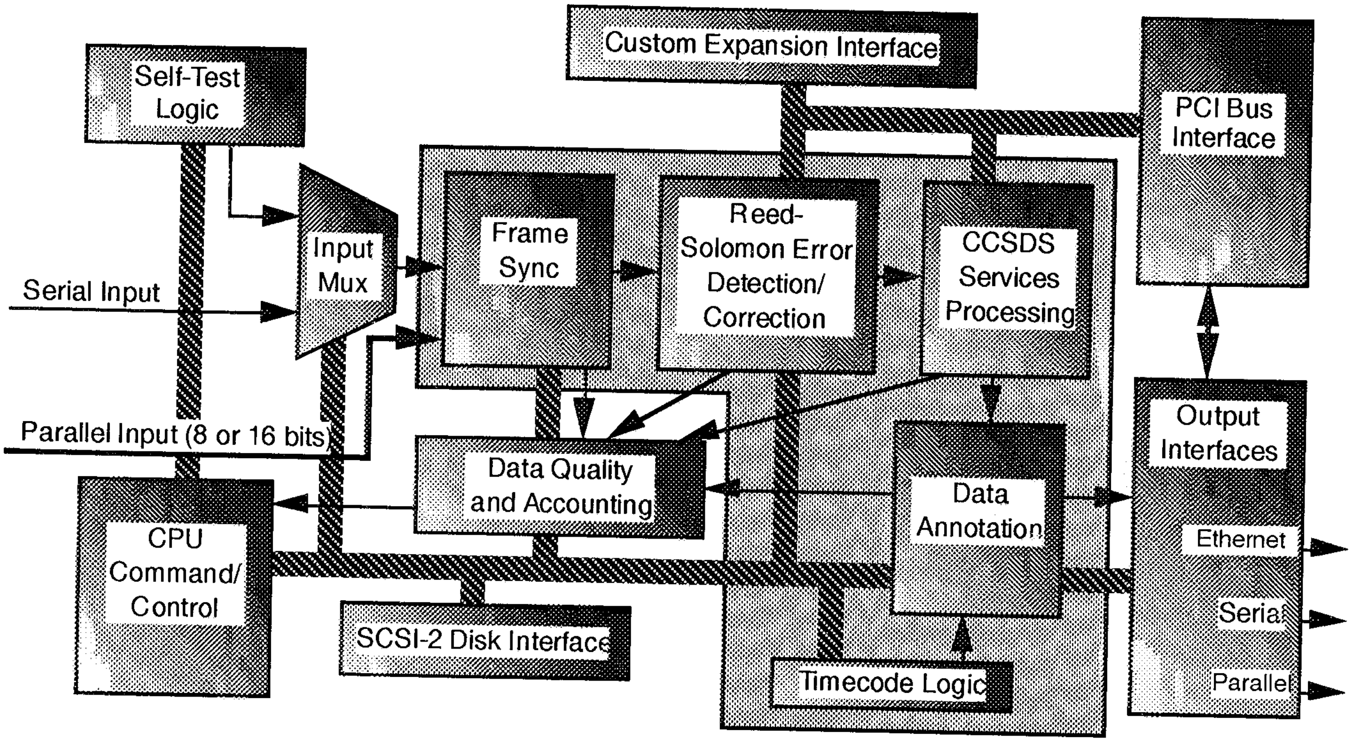

Figure 4. CCSDS Protocol Processing Subsystem
Detailed Block Diagram

The automated workstation-based operation and control software provides an interface to control the antenna, RF and CCSDS Protocol Processing system elements. It communicates with these elements through an ethernet port. The command and control software has a graphical user interface and on-line help to allow a non-expert (in data systems) to configure and operate the system elements with minimal training. Any number of users may be configured to receive data products and status from the CCSDS Protocol Processing subsystem.

3. SYSTEM DEVELOPMENT

Development of the system is already under way. The development plan calls for a three stage approach.

Stage 1 consists of a Commercial Off-the-Shelf (COTS) antenna, COTS Virtual Module Eurocard (VME)-based RF receiver, a highly integrated single motherboard CCSDS protocol processing subsystem and Version 1.0 of the command and control software running under VxWorks. This software will include limited science processing capabilities including level zero processing. Targeted release date is May 1995.

Stage 2 consists of a COTS antenna with a phased array antenna for generating ephemeris data, VLSI digital receiver, a highly integrated single motherboard CCSDS protocol processing subsystem and version 2.0 of the command and control software. This software will include expanded science processing capabilities including limited browse product generation. Targeted release date is January 1996.

Stage 3 will explore the use of a phased array antenna to acquire data while including all of the functionality of Stage 2. In addition, version 3.0 of the command and control software will include hardware support for accelerating higher level processing (levels 0 and 1) and refined software for generation of browse data products. The targeted release date is October 1996.

4. TYPICAL OPERATIONAL SCENARIO

The complete direct broadcast acquisition system, including antenna, will be small enough to fit into a conversion van for transportation. Once setup and operational, all equipment except the antenna can be contained in the same van.

Operationally, the system can easily be configured to handle different data formats and missions. Upon startup, the system performs an end to end self -test. This is done by generating a typical data stream and processing it through the system. System statistics are then accumulated and compared to the expected results and a dump of selected frames/packets are compared on a bit by bit basis to the expected results. Any differences are flagged and the user is notified of the error detected, the subsystems which are affected and the probable cause of the error.

After the system has passed self-test, if may be configured to process telemetry data. A configuration file that has been previously generated may be downloaded to the system or the user may generate a new configuration file. This file contains the high level mission information that the system needs to be aware of to recognize the format of the telemetry stream. These parameters include but are not limited to the frame sync pattern, the frame length, the type of error detection/correction used and the types of services to be performed. This high level information is translated by the operation and control software to low level hardware commands to correctly configure the system.

The system is now ready to process data. The antenna acquires a signal as the EOS spacecraft is passing overhead. The signal passes through a low noise amplifier and is then down-converted to an IF. At this point, the data is digitally sampled and the demodulation is done using digital processing algorithms. The bit synchronizer takes the output of the demodulator and produces a clock and serial data bitstream. Viterbi error correction then takes place and the data is sent to the frame synchronizer which recognizes the frame sync pattern and delimits the data based on a user defined acquisition strategy. The data is then optionally bit transition density decoded.

The delimited frames are then sent to the error detection and correction subsystem. This subsystem provides deinterleaving and block error correction using the Reed-Solomon code on either the entire frame only, the header only, or both.

After error detection and correction, the frames are sent to the CCSDS service processing subsystem which allows any of the various CCSDS specified services to be performed on the frames on a Virtual Channel Identifier (VCID) basis. These services include Virtual Channel Data Unit (VCDU) service, Insert service, VCA service, Bitstream service, Path packet service and Encapsulation service. These data products are then routed to the user over standard user network interfaces.

All quality and statistics information is accumulated by the system and provided to the workstation for display to the user. Various flags and limits may be set up which trigger system events. For example, if the system sees many frames which have uncorrectable data passing through the system, false synchronization could have occurred, in this case the system could be set to respond by forcing a back-to-sync signal that would allow the system to re-acquire sync and disregard the false sync.

5. SCIENCE PROCESSING

After the low-level CCSDS Processing (e.g. packet extraction) has been performed, this raw sensor and ancillary data must be transformed into working models of the complex whole-Earth systems called standard products. In addition, summary information about the data called browse products may be generated to allow the scientist determine which data may be of interest. The process of going from raw sensor data to browse products to integrated Earth models involves several levels of processing.

Level 0 processing involves reconstructing complete sensor scenes and engineering data from data packets, including packet resequencing and transmission error detection and correction. Level 1 processing involves radiometrically and geometrically calibrating the data due to atmospheric anomalies, sensor noise, and spacecraft attitude or orientation. Level 2 processing involves transforming the data into their intended sensor units (e.g., radar backscatter cross section, brightness, or temperature). Then, depending on the target application, the data are mapped into a set of scientifically meaningful features. This classification can be as simple as taking the ratio of two channels to quantify biomass or as complex as statistical classification of the spectral signatures to known features such as land use categories. Level 3 processing takes into consideration dynamic issues by mapping the data to a uniform space-time coordinate system. This often involves the interpolation of missing values due to orbital track characteristics and the mosaicking of multiple orbits. Processing at higher levels becomes highly application-specific involving various types of numerical code.

The EOS Direct Broadcast Acquisition System described in this paper will be capable of performing the various levels of science processing at limited data rates. In addition, it will be capable of producing summary metadata known as browse products. These browse products provide a low-resolution, low-accuracy view of the data to assist in determining which data may be of interest to the scientist. Giving an earth scientist the ability to acquire raw data directly and perform these data processing algorithms to generate browse products on a local machine will allow quicker data validation and refinement of models and simulations.

6. CONCLUSION

Low cost acquisition of EOS direct broadcast data is soon to be a reality. NASA Goddard Space Flight Center is using high-performance Complementary Metal Oxide Semiconductor (CMOS) VLSI circuitry and parallel processing algorithms to provide a transportable acquisition station at unprecedented levels of performance versus price. The integration of this station with intelligent software that allows a non-expert to configure the system and process data will allow not only a large community of earth scientists access to real-time science data but also extend the capability to a whole new class of users.

7. REFERENCES

1. Asrar, G., Dokken, D., "EOS Reference Handbook", 1993.

8. NOMENCLATURE

CCSDS	Consultative Committee for Space Data Systems
CMOS	Complementary Metal Oxide Semiconductor
COTS	Commercial Off-the-Shelf
EOS	Earth Observing System
GSFC	Goddard Space Flight Center
IF	Intermediate Frequency
NASA	National Aeronautics and Space Administration
PCI	Peripheral Component Interface
RF	Radio Frequency
VCID	Virtual Channel Identifier
VCA	Virtual Channel Access
VCDU	Virtual Channel Data Unit
VME	Versa Module Eurocard